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New French Tethered Balloons of Large Volume: Development, Handling Techniques, and Safety Problems

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Contents

34. New French Tethered Balloons of Large Volume: Development, Handling Techniques, and Safety Problems

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Abstract

After a short historical review of French aerodynamically-shaped tethered balloons (balloon with ballonet, Caquot's type (1915), and dilatable balloon, Letourneur's type (1925), the different steps in the resumption of use of such balloons in France, which began in 1962, are presented (all materials having been completely destroyed during the Second World War). New-type requirements for heavy payloads have led to the development of operational balloons of several thousand cubic meters capacity by 1966, followed by others of yet larger volume.

A brief description of the balloons used is given. Each has a soft expendable hull of three-to-one fineness ratio, with three tail-fins in "Y" configuration equally spaced and air inflated, as well as accessory equipments.

After manufacture, these balloons are indoor-inflated with air to test gas tightness, and afterwards with hydrogen in order to make various adjustments.

The use of large quantities of hydrogen, together with synthetic fabrics (material highly electrifiable) requires unusual safety techniques to make the balloons as safe as possible.

Fitting of accessory apparatus and hydrogen inflation are carried out on special areas made of concrete. This allows easy handling of the balloon with the help of two winches and many pulleys, aided by the numerous handling ropes attached all along the hull.

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In field operation the balloons are constantly controlled, and great care is taken because of their vulnerability to bad weather and to aging of their structural materials. Two methods of anchorage are used: (1) tightly pulled down to the ground on the inflation areas, or (2) in flight, at low altitude, tethered by a single cable.

Throughout the paper, special emphasis is given to incidents which happened during the numerous test-series in France and abroad.

34.1 INTRODUCTION

During the First World War, tethered balloons were widely used as posts for observation of enemy lines.

This type of equipment gave such good service to the Allies that it was religiously preserved in France, where it was still in operation at the beginning of the Second World War. Tethered balloons were, naturally, good targets for the German Air Force, who shot down a great number; the remainder were afterwards completely destroyed or looted by the invaders.

When the use of captive balloons was again necessary in France, practically nothing was left of the past glory of military aerostatics.

Tribute must be paid at this point to some former balloon specialists (Forichon et al, and Caquot private communications), who started valiantly to work, and to some small wartime balloons rescued from a surplus dump. The revival of tethered balloons was thus possible in our country.

Resumption began in 1962, at Chambaran (Isère) where, with balloons 20 years old and of 90 to 550 and 1,000 m^3 capacity, we elaborated the handling techniques and again invested the accessory apparatus (hydrogen inflation, anchorage, winches, pulleys, cables, valves, etc.) taking into account new-type requirements. In 1964, an experimental balloon of 1,500 m^3 capacity, manufactured by Société Aérazur (Forichon et al) permitted the continuation of our efforts. Numerous test-series were then made, either on land or on sea, for the development of both the new balloon and its auxiliary apparatus.

This balloon soon proved to be satisfactory, and served as a model for those of larger capacity which followed (4,000, 6,500, 10,000 and 14,000 m^3).

34.2 NEW FRENCH TETHERED BALLOONS OF LARGE VOLUME

For the construction of soft captive balloons, two techniques are used: (1) balloon with ballonet, BB-Caquot's type (1915), and (2) dilatable balloon, BD-Letourneur (1925). The advantages of the latter (Jouglard, 1933), constant buoyancy lift, constant center of buoyancy and constant gas mass, have led to its choice.

34.2.1 Description of an Aérazur Balloon

Figures 34.1, 34.2, and 34.3 show schemes of a typical balloon, and a description of the parts called out in these figures is given in the Legend for Figures 34.1, 34.2, and 34.3 [parts (1.1) through (1.27), (2.1) through (2.8), (3.1) through (3.11), and (4.1) through (4.8)]. Although in the course of development during the last six years, the technique of manufacture has changed somewhat in order to meet new requirements, balloons designed and constructed by Société Aérazur of Paris (Forichon et al) have the following characteristics in common:

The hull (1), having the theoretical shape of two half-ellipsoids joined at the maximum diameter, is made of single-length gore fabric bonded with adhesive and seamed.

The fineness ratio L/D is in the range 3.1 to 3.2. Two extensible gores (1.4) and (1.5) with bellows and elastic ropes, situated at the lower part on the right and the left sides, permit extension which is completed when pressure in the hull P_c is about 3.5 mb (measured near the hull bottom).

The introduction of gas is effected by means of two valves, one for high inflation flow rate (1.16) and the other for refloat inflation (1.19) at lower flow rate. In case of accidental escape of the balloon, a calibrated relief valve (1.21) avoids a possible hull burst while a device (1.24) situated at the highest point and electrically monitored by a barocontact adjusted for a given altitude, insures rapid emptying.

Remarks: The classical rip panel formerly utilized has been finally discarded because of possible gas leaks caused by defective sealing.

The tail-fins, consisting of soft air-inflated longitudinal ribs are equally spaced in "Y" configuration, the lower one being vertical; they communicate with each other by a duct (1.14) and are removable. The constant pressure of 8 mb maintained automatically by an electrical blower (3.4) [with a standby ejection pump (3.10)] gives them the necessary rigidity which combined with the action of cross-bracings and guy ropes (made of nylon) permits maintenance of normal shape. During ascent, one or several calibrated relief valves (3.9) limit this pressure to the initial value.

The double fan-shaped harness comprises flexible metal cables (either having or not pulley-blocks) attached to the hull by gussets of reinforced fabric in the shape of goose feet, and joined at a point by a V-shaped piece from which the main mooring cable starts. This harness is adjusted so as to give to the longitudinal hull axis a positive incidence of 8° at zero wind speed.

Balloon handling on the ground (inflation and anchorage) are made possible by means of a large number of nylon handling ropes attached all along the hull by the help of glued gussets (1.7).

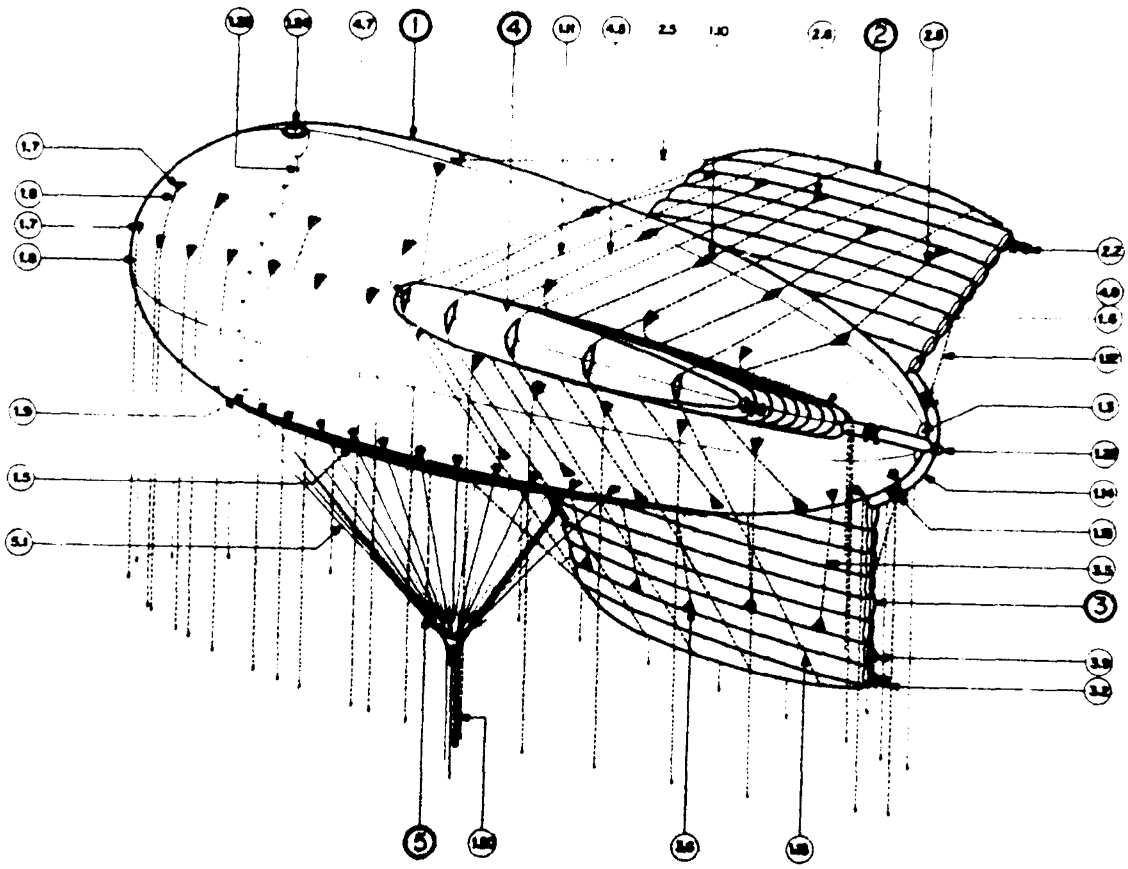

Figure 34.1. Dilatable ARZ Balloon (Side View)

Legends for Figures 34.1, 34.2, and 34.3

1 HULL

1.1 Hull gore
1.2 Bow disc
1.3 Stern disc
1.4 Right extensible gore
1.5 Left extensible gore
1.6 Fin attachment
1.7 Handling guy gusset
1.8 Handling guy
1.9 Harness cable gusset
1.10 Fin guyline gusset
1.11 Upper bracing
1.12 Right lateral bracing
1.13 Left lateral bracing
1.14 Tail-fins duct
1.15 Duct link

1 HULL (Ctond.)

1.16 Inflation valve
1.17 Purity and pressure teat
1.18 Inflation sleeve and man hole
1.19 Refloat valve
1.20 Refloat hose
1.21 Relief valve
1.22 Fin air relief valve
1.23 Emptying hole
1.24 Rapid-emptying valve
1.25 Electrical cable for rapid-emptying valve
1.26 Dilation gauge band
1.27 Scale for in-flight pressure measurement

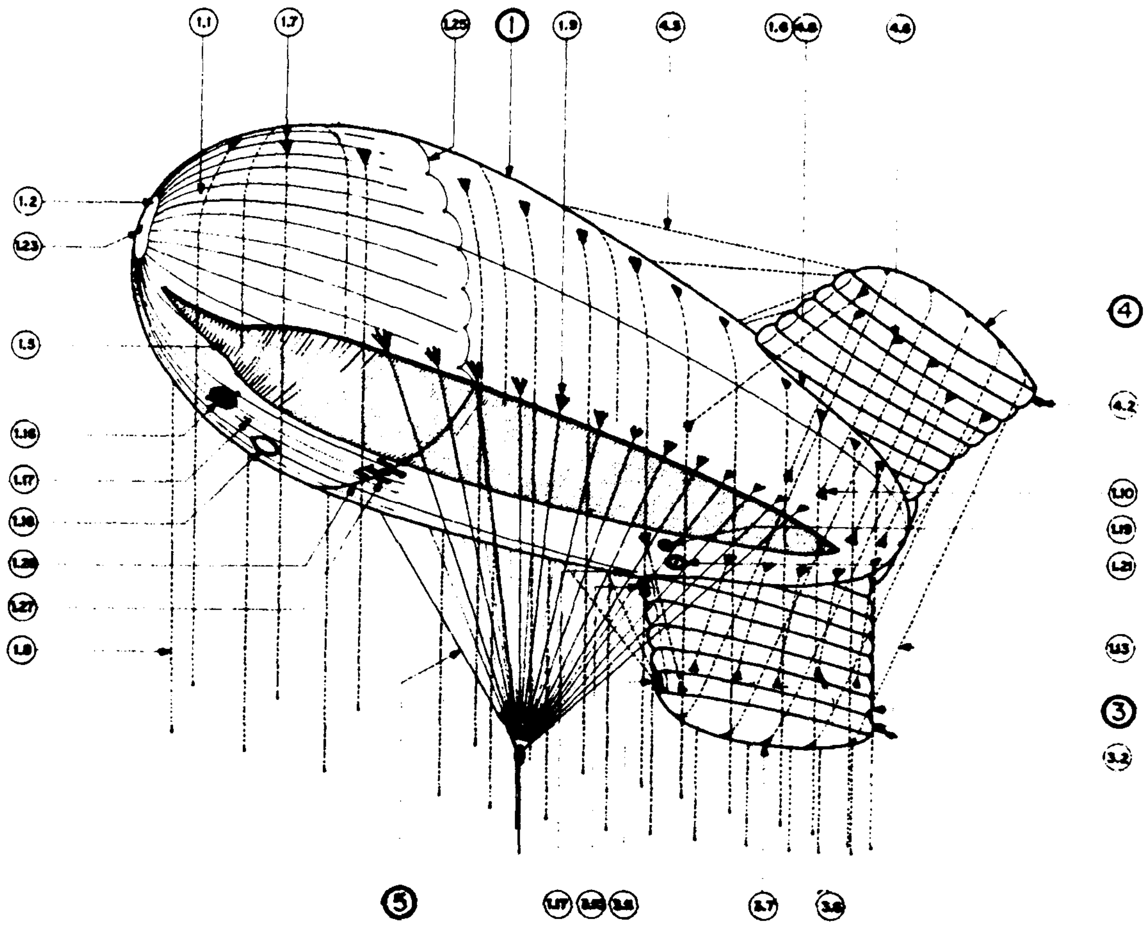

Figure 34. 2. Dilatable ARZ Balloon (Side View)

Legends for Figures 34. 1, 34. 2, and 34. 3 (Contd.)

2 RIGHT LATERAL FIN

2. 1 Salmon (fin extremity)
2. 2 Deflating sleeve
2. 3 Pressure teat
2. 4 Lower bracing
2. 5 Upper bracing
2. 6 Bracing gusset
2. 7 Bracing patch
2. 8 Fin attachment

3 LOWER FIN

3. 1 Salmon
3. 2 Inflation sleeve
3. 3 Pressure teat
3. 4 Right lateral bracing
3. 5 Left lateral bracing

3 LOWER FIN (Contd.)

3. 6 Bracing gusset
3. 7 Bracing patch
3. 8 Fin attachment
3. 9 Air relief valve
3. 10 Air ejection pump
3. 11 Electrical blower

4 LEFT LATERAL FIN

4. 1 Salmon
4. 2 Deflating sleeve
4. 3 Pressure teat
4. 4 Lower bracing
4. 5 Upper bracing
4. 6 Bracing gusset
4. 7 Bracing patch
4. 8 Fin attachment

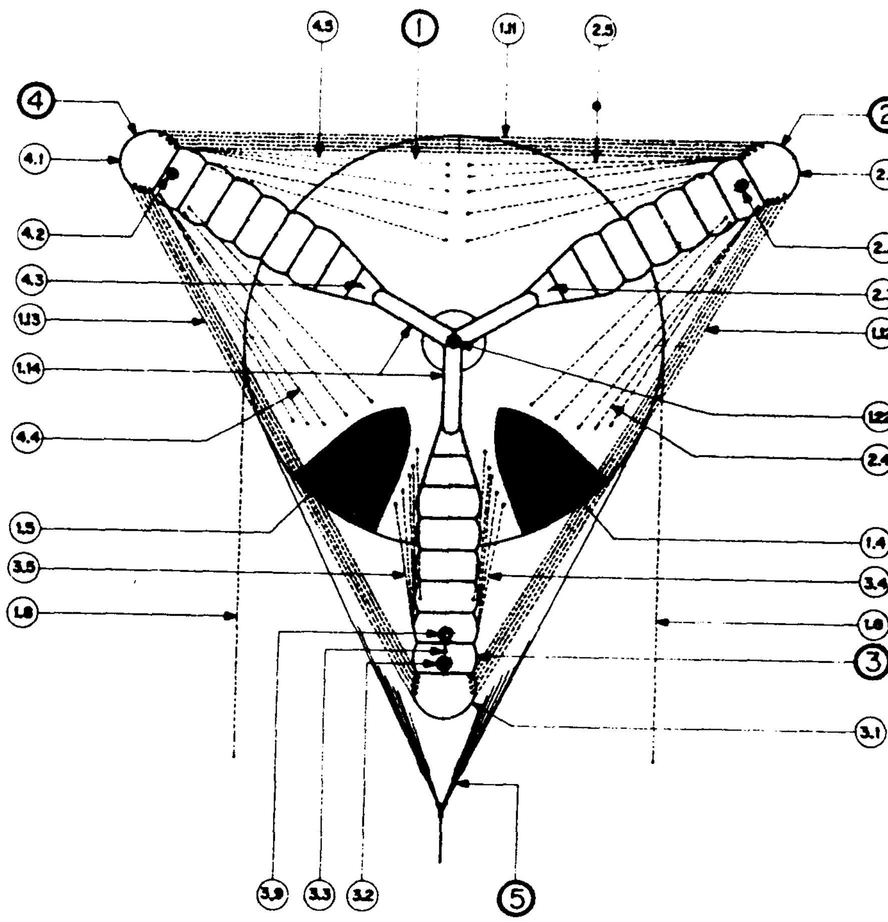

Figure 34. 3. Dilatable ARZ Balloon (Stern)

34.2.2 Main Characteristics of an ARZ Balloon

By way of example, here are some characteristics of an ARZ balloon of 6,500 m^3 capacity:

(1) Hull

(a) Length: L = 52 m

(b) Maximum diameter: D = 16 m

(c) Capacity: P_c = 3.5 mb, 7,400 m^3

(d) Capacity: P_c = 2 mb, 6,560 m^3

(e) Angle of incidence: i = +8°

(f) Number of gores: 51

(2) Tail-fins

(a) Volume of one fin: 360 m^3, length 18 m, height 15 m, area of one side 175 m^2.

(b) Total weight of the balloon fully equipped = 2,300 daN (deka Newton).

(3) Residual lift force under the V-shaped piece, at sea level and 25°C, hydrogen inflated, zero wind speed, RLF : 4,800 daN.

34.2.3 Aerodynamic Coefficients

Figure 34.4 shows the aerodynamic coefficients: drag C_x, lift C_z = f(i), and yawing-moment C_N = f(j) resulting from wind tunnel measurements on a rigid model made of wood at scale 1/60. Wind speeds have reached 28 m/sec. Curve 1 corresponds to hull with fins, curve 2 to hull along; i and j are, respectively, angle of incidence and yaw angle. The high values of the ratio C_z/C_x may be noticed; an important extra lift-force due to wind speed is added to the buoyancy force.

Balloon stability in yaw motion is a delicate point; experiments have shown the desirability of having restoring moments which should be not too great.

These excellent aerodynamic properties must not, however, obscure the fact that the real balloon is soft and is deformed by strong winds (particularly the tail-fins), and that exact aerodynamic similitude is far from being achieved. Moreover, a compromise must be found between the need to obtain a good aerodynamic profile and the need to limit the wind forces on tethering cables.

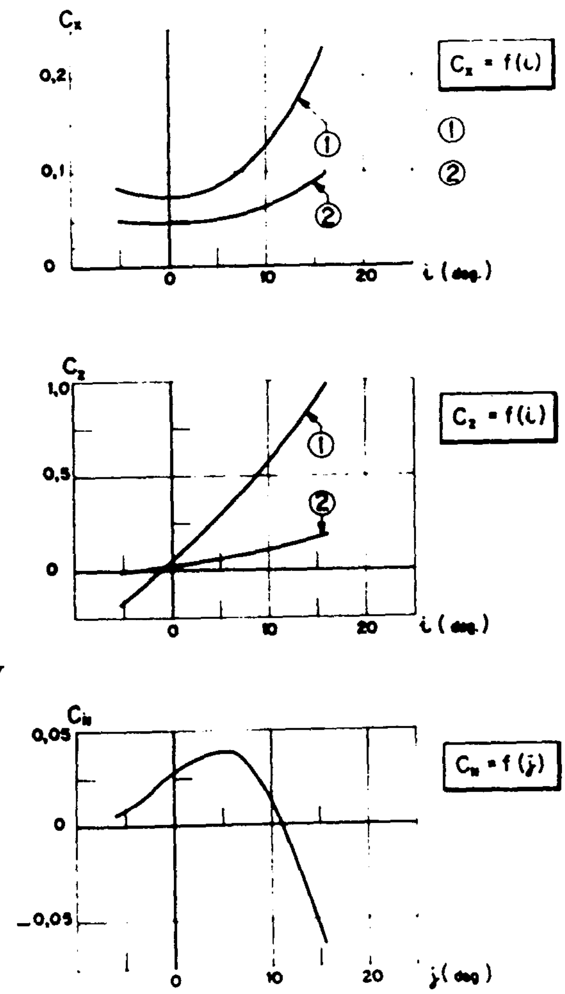

Figure 34.4. Aerodynamic Coefficients. (1) Hull with tail fins, and (2) hull without tail fins

34.2.4 Fabrics

The fabrics used are synthetic materials offering great mechanical strength together with high hydrogen tightness. They consist of a substrate of single or double nylon coated on the outside by yellow urethane, and on the inside by neoprene.

Here are some characteristics:

	Hull	Tail-fins
Mass g/m^2	380	280
Dead load strength daN/5 cm	250	150
Hydrogen permeability ℓ/m^2-24 h	3	5

Note: Mechanical strength warp and fill are not very different; the above figures correspond to the average.

In marine tropical climates, fabrics and adhesive bonds age very rapidly. Removal of the urethane coating occurs in the laboratory at 70°C temperature and 90 percent relative humidity. The utilization of these synthetic fabrics, instead of cotton or silk, introduces a new danger when hydrogen is used because of their high capacity for electrostatic charge. Fortunately, the surface electrical resistivity decreases rapidly when the atmospheric humidity increases.

Let us note that the daily hydrogen losses for our balloons are of the order of 1/100 of their volume. Gas refilling is thus necessary every 3 or 4 days, in order to maintain the hull pressure at a sufficient value.

34.3 HANDLING OPERATIONS

34.3.1 Inflation and Anchorage Area (Figure 34.5)

Note: The parts called out in Figure 34. 5 are given in the Legend for Figure 34. 5, parts (1) through (12).

After manufacture, balloons are first indoor air-inflated (hull and tail-fins), for a general inspection and then they are inflated with gas in order to adjust the harness and accessory equipment.

This operation, initially carried out with some difficulty outdoors, is now easily made under an old dirigible shed, which offers the necessary space. Balloons thus leave fully tested, with the accessory apparatus well adjusted, and are then ready for service on a remote site, to which they are transported in a special packing under a dry atmosphere.

The areas where inflation and anchorage are carried out, oriented in the direction of the prevailing wind, are made of concrete with a smooth surface. They have three winches, a central one (1) permitting ascent, and two lateral ones (6) permitting anchorage on the ground.

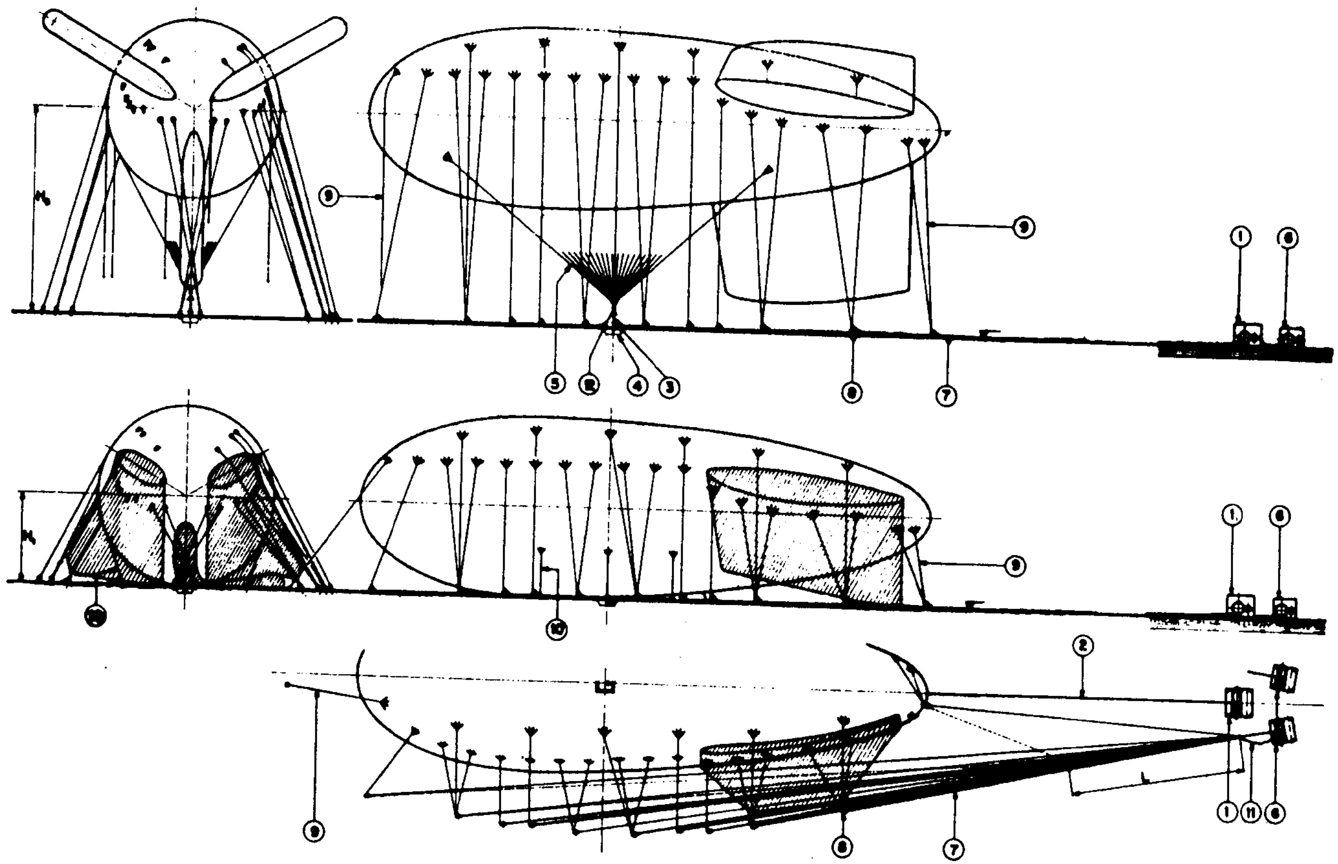

Figure 34.5. Area of Inflation and Ground Anchorage

Legend for Figure 34. 5

1. Central winch	8. Handling line pulleys
2. Central winch cable	9. Handling lines
3. Fairlead	10. Anti-roll anchorage ropes
4. Fairlead hole	11. Safety mooring cable for lateral winch
5. Harness	12. Safety mooring cable for central winch
6. Lateral winches	
7. Anchorage cables	

Balloon handling is made easier by the great number of nylon guy lines (9) attached all along the hull and joined on each side with the help of cables to a point from which starts the cable of the corresponding lateral winch, each of them passing first round a pulley block (8). When the wind does not blow in the direction of the area axis, this technique permits bringing in the balloon from positions up to 90° of the axis. Walls to provide wind-breaks arranged around the area make inflation possible, even at wind speeds greater than 10 m/sec.

Ground anchorage of the balloon in the event of bad weather, or for repair, is thus made easy. The tail-fins are then deflated and moored tightly, and all necessary safety-measures can be taken. However, in strong cross winds, tail-fins and hull can suffer. Such an anchorage has stood well, however, against cross winds of speeds greater than 30 m/sec., during an entire night under heavy rain.

34.3.2 Safety Problems Related to the Use of Hydrogen

The hydrogen used has a purity greater than 99. 6 percent, and is contained in cylinders under a pressure of 200 bars. It is introduced into the hull through the inflation valve (1. 16, Figure 34. 2) (also see Figure 34. 6) after having been depressurized to pressure slightly above atmospheric pressure. The flow rate is 5,000 to 10,000 STP m^3/h, and the desired hull pressure is 2 mb (at the bottom). The inflation operation is delicate because of: (1) fire risk, and (2) possible wind action. Operations are not carried out if the wind speed exceeds 10 m/sec with the wind-break walls, and 7. 5 m/sec, without them. Knowing that hydrogen is inflammable in air at a very low ignition energy (10^{-5} Joule) within the limits of 4 to 74 percent, detonating from 18 to 59 percent, the classical principles of safety have been strictly applied: (1) avoid inflammable or detonating mixtures, and (2) eliminate ignition sources.

All metal parts of the area are electrically connected and grounded. Great care is taken to maintain a high atmospheric humidity by constant watering of known dangerous places, in order to eliminate electrostatic charges which could

Figure 34. 6. Inflation of an ARZ Balloon with Hydrogen

be generated on synthetic fabrics. The crew wear asbestos clothes and work under the careful supervision of firemen.

In spite of these precautions, an accident did occur during a balloon inflation, and 4,000 STP m^3 of hydrogen burned within about ten seconds. Thanks to rapid gas diffusion upwards, injury to personnel was fortunately light.

As laboratory experiments have shown, the fire risks due to a small hydrogen leak on the hull are relatively small (Guizouarn and Perroud, 1963).

During operation, the purity of the hydrogen in the hull is frequently checked with the help of a conductivity-type apparatus.

34.3.3 Balloon Ascent (Figure 34.7)

Note: The parts called out in Figure 34. 7 are given in the Legend for Figure 34. 7, parts (1) through (12).

The balloon prepared in this way on the inflation area is transported on to the launching site by a special truck, having on its rear end a winch and a fair-lead permitting ascent to low altitude. In the case of marine launching sites, the truck and its aerial load are embarked on to a flat bottomed landing craft (French Navy type LCT). The transshipment is made on to the main barge (see Figure 34. 7).

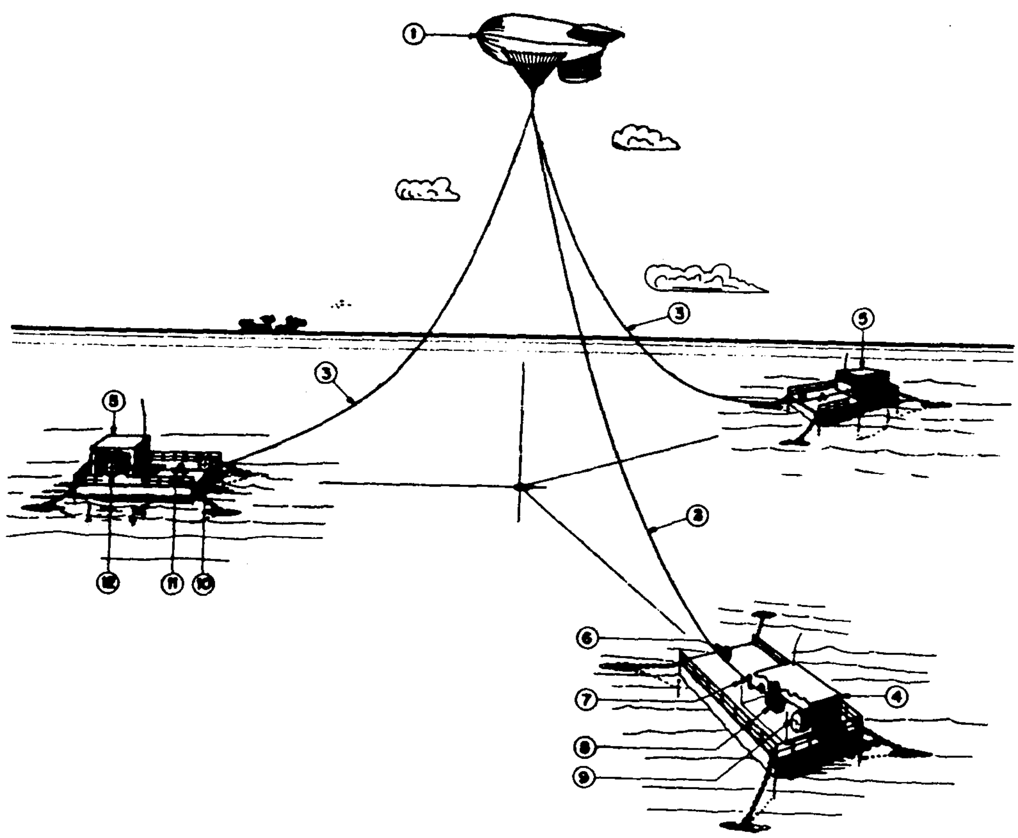

Figure 34. 7. Flying the Balloon on a Tripod of Cables

1. Balloon
2. Main tethering cable
3. Positioning cable
4. Main barge
5. Positioning barges
6. Oscillatory fairlead
7. Cable tensiometer
8. Capstan of main winch
9. Drum for cable storage
10. Oscillatory fairlead
11. Cable tensiometer
12. Positioning winch

Although very practical in a calm sea, this method of transport can become dangerous in a heavy sea, by reason of the whiplashes given to the cable by the action of the waves, or, more so, by wind action which increases the drag on the boat.

When a fixed position in space is required, it is necessary to make use of a regular tripod of cables (see Figure 34. 7). The vertices of the equilateral triangle on the sea are then provided by barges (4) and (5), moored to the bottom in shallow water and each carrying a winch. The main barge (4) and its winch serve for attachment and raising of the gondola and for placing the balloon on standby in the air, and the secondary winches for positioning. The winches used have each a capstan (8) and a storage drum (9). An electric motor gives a constant speed of 0. 3 m/sec to the cable. The fairleads (6) and (10) are able to oscillate about a longitudinal axis, and are designed so that it is practically impossible for the cable to leave the pulley. Made up from twisted wires of special, high-tensile steel (200 daN/mm^2), the main tether cable (2) and the positioning tether cables (3) work respectively at 1/3 and 1/2 the rupture limit under the most unfavorable case for normal conditions. The cable tension at ground level is continuously measured by a three-pulley tensiometer.

34.4 PERFORMANCE IN FLIGHT

In flight, the following parameters are transmitted to the ground and recorded: (1) hull and fins pressure, (2) speed and direction of wind relative to balloon, and (3) warning of malfunction of one of the systems for refloating the fins (pressurizers).

The behaviour in flight is related to the aerodynamic characteristics of the balloon and to the forces applied to it. Addition of a tail parachute in certain cases improves the stability of the balloon in a wind.

34.4.1 Flight on a Single Cable (Figure 34.8)

This configuration is most often used while the balloon is "on standby" in the air. Thus, a balloon tethered by a 150 m cable can undergo, without too much strain or hazard, winds of up to 20 m/sec (lateral displacements reaching 40 m). Beyond that point, sideways drift of the balloon is so great that it can turn across the wind. The hull then curves in the form of a banana, the fins are deformed, and the aerodynamic qualities of the balloon are lost.

It can either remain in this position at low altitude, exercising a very strong force on its cable, which then makes a low angle with the horizontal, or it can continue its fall until it hits ground and is wrecked.

The good behaviour of a balloon in flight depends strongly on wind characteristics. In this respect, sudden changes in wind direction prove to be much more harmful than rapid changes in wind speed.

34.4.2 Flying on a Tripod of Cables

The stability of a tripod formed by three cables depends on the forces acting at the triple-point. The stability limit of this tripod, which also depends on the relative direction of the wind, is reached when one of the cables makes a

Figure 34. 8. Dilatable Balloon ARZ in Flight at Wind Speed of 10m/sec

zero tangential angle with the horizontal at its point of anchorage. After that, it is impossible to bring the triple-point to the summit of the imaginary regular tetrahedron by pulling on the cables.

For the balloons which have been used, we have calculated the limits of stability. The result of such a calculation is given in Figure 34. 9. This diagram deals with a specific tripod (altitude of the triple-point H = 600 m, diameter and weight of cables being known). It allows the critical wind speed Vc, as a function of its direction, and the vertical force Fv applied to the summit of the three cables to be determined. (Here the wind is defined as the direction of its force.) For example, if the wind direction is 70° and the force Fv is $4.5\ 10^{4}$ Newton, the limit of stability of this tripod will be reached for a wind of 12 m/sec = Vc.

The horizontal displacements of the triple-point around the zero-point are equal to 0. 075 H in the critical conditions of wind. For wind speeds lower than the critical value the displacements are, of course, less.

The variations in altitude of the triple-point are in the neighbourhood of one-quarter of the above-quoted values.

For wind speeds above the critical value, the cables extend and contract alternately, and the sudden tensile forces thus set up in the cables can reach then rupture limits, setting free the balloon with its load.

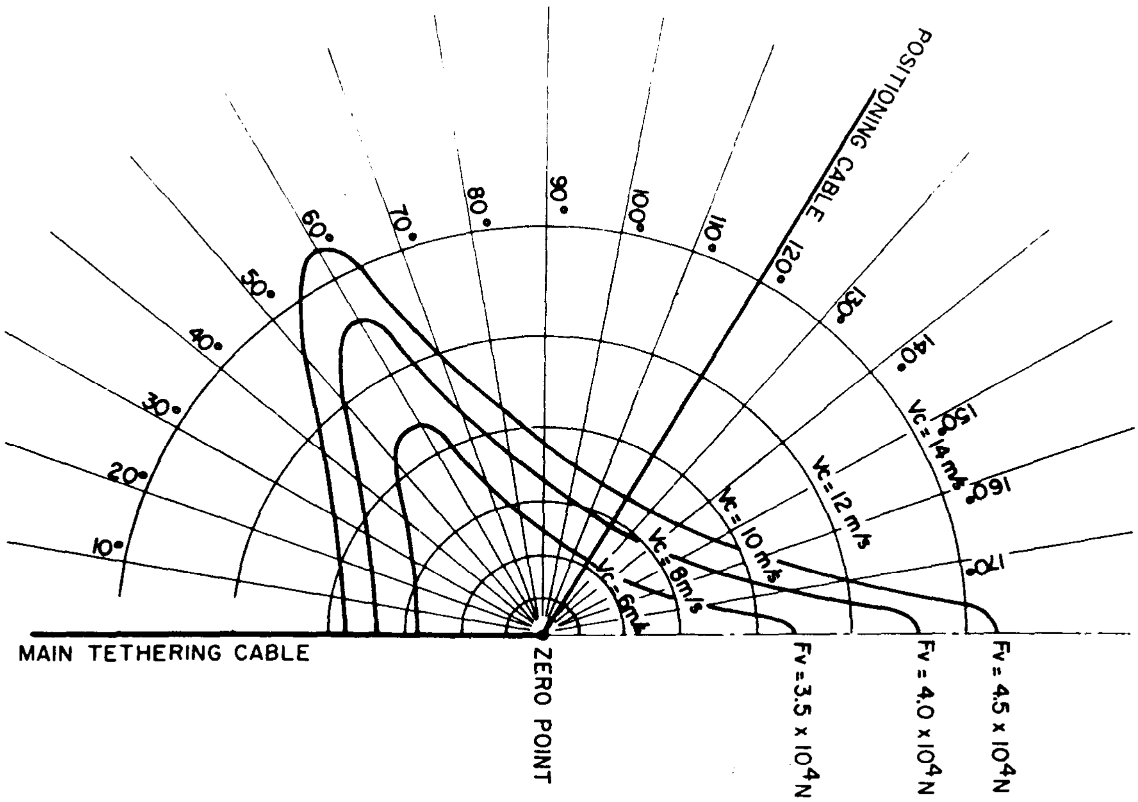

Figure 34. 9. Limits of Stability of a Tripod. Altitude H = 600 m.

It may also be noted that the stability of the tripod has a direct effect on that of the balloon itself, the sideslip being limited if the tripod is stable.

Finally, test-series for measurements of flight parameters have been carried out, but analysis of the results has proven to be delicate, by reason of the interdependence of these parameters.

34.5. CONCLUSION

Requirements of a new type have permitted France, cradle of Aerostatics, to undertake during the last six years the development of tethered balloons of large volume. These balloons, having an expandable hull and carefully manufactured by Société Aérazur of Paris (Forichon et al), have shown outstanding performances in wind speeds up to 25 m/sec.

Inflation with hydrogen has been possible, in spite of the use of synthetic fabrics (material highly electrifiable), as a result of the inflation techniques we have developed. Nevertheless, a potential danger still remains which should always be kept in mind. Therefore whenever it is possible, helium must be preferred.

Accessory apparatus, handling equipment and handling techniques tested out during the numerous test-series in France and abroad, are now entirely satisfactory.

In memoriam: M. Pierre Leroy (1893-1969), recently deceased, spent more than fifty years of his creative genius in the service of French Aeronautics. He was instrumental in manufacture of the balloons at Société Aérazur of Paris, of which he was Technical Director.

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